EFFECT OF IR INTENSITY AND AIR TEMPERATURE ON EXERGY AND ENERGY AT HYBRID INFRARED-HOT AIR DRYER

Article Highlights

- Increasing IR radiation intensity caused improvement in energy and exergy efficiencies
- Highest energy and exergy efficiency values were 13.50 and 62.26%, respectively
- The lowest energy and exergy efficiencies were 3.95% and 20.37%, respectively

Abstract

The present study analyses energy and exergy consumption for drying dog-rose flowers using a hybrid infrared and hot-air dryer at three IR (infrared) radiation levels, three airflow velocities, and three drying temperatures. Results showed that energy and exergy efficiencies sharply increased at the beginning of the drying process. Energy loss, exergy destruction and exergy loss increased with increasing IR radiation, rise in the incoming air’s temperature, and decrease of the airflow velocity. The average of lowest energy and exergy efficiencies were 5.76 and 3.98%, respectively, observed at the air temperature of 40 °C using an IR radiation of 0.22 W/cm² and an airflow velocity of 1 m/s. The average of highest energy and exergy efficiency values were 49.92 and 23.65%, respectively, observed at the beginning of the drying process at 60 °C using 0.49 W/cm² IR radiation and an airflow velocity of 0.4 m/s.

Keywords: dog-rose, air temperature, IR intensity, exergy, energy, drying.

Today, most developed countries are conducting extensive research on identifying their own flora and the medicinal plants used in other countries. Due to the rapid growth of fungal and bacterial populations in plant tissues, keeping fresh medicinal plants for long periods is a challenging task. By evaporating moisture content to a specific threshold, drying process could extend the shelf-life of medicinal plants while maintaining their active ingredients. Research shows that using hot airflow is extensively applied as a drying practice for agricultural products and medicinal plants. This method is accompanied by limitations such as high energy consumption, long drying time, and high drying temperature. Research on energy consumption of hot-air dryers showed that medium value was 6000 kJ/kg for evaporating moisture in food products [1,2]. Besides high energy consumption throughout the process, applied methods and equipment suffer from low efficiency. Therefore, it is essential to shift towards using dryers with higher productivity and energy efficiency. The hybrid IR-hot-air (IRHA) technique is a method that both maintains product quality and brings about the high energy efficiency and low energy consumption [3,4]. The hybrid IRHA dryers can be used for both delicate and non-delicrate products using controls for IR radiation and incoming air temperature. The hybrid IRHA technique accelerates the drying process, increases product quality and improves drying efficiency [5]. Most agricultural products have been successfully dried using this system including mushroom slices [3], blackberry leaves [6], jujube slices [7], onion slices [8], apple slices [9], peas [10], stale breads [11], and potato slices [12]. Lutovska et al. [13] and Zhu and Jiang [14] performed their research on drying of peas and sweet potatoes, respectively. Also, Motevali and Minae [15]...
investigated the effects of microwave pretreatment on the energy and exergy utilization in thin-layer drying of sour pomegranate arils and the obtained results showed that energy utilization and energy utilization ratio increased with time, while exergy efficiency decreased. Energy utilization and drying time decreased considerably with microwave pretreatment of pomegranate arils and the minimum values of exergy loss and exergy efficiency were obtained for 200 W microwave output power.

In this study a hybrid IRHA dryer was used to assess drying properties and quality of dried products by altering the effects of radiation distance and intensity, airflow velocity and temperature, and size of products. Results showed that, by increasing IR radiation intensity, increasing inflow temperature and reducing inflow velocity, products lost moisture faster thus reducing the drying time.

The study of drying kinetics for agricultural products is not sufficient in order to get a complete insight about a dryer unit. Therefore, thermodynamic analyses (particularly energy and exergy analyses) are required for designing, analysing and optimizing a heating and drying system [16]. Energy and exergy analyses allow for a more precise study on energy variations and quality in a dryer system. The first law of thermodynamics was used to analyse energy consumption and energy efficiency of industrial dryers. An energy analysis provides no information about the energy quality, thus it is useless for designing an optimized system. One of the main purposes of designing and optimizing industrial drying processes is to consume the least amount of energy possible for removing moisture before reaching desired moisture conditions. Thermodynamically, exergy is defined as the maximum useful work generated by a system [17-19]. The purpose of such analyses is to understand and improve the entire system and applied equipment [20,21].

Aghbashlo [22] developed a simulated model for analyzing the exergy of a continuous-flow IR dryer. It was shown that exergy increases by raising the temperature of the IR source, and also exergy decreases by increasing the airflow velocity. Results showed that exergy destruction also increased by increasing the temperature of the IR source. Energy and exergy analyses of red pepper slices showed that higher temperatures increased energy consumption, whereas both energy consumption and energy consumption ratio decreased over time. Exergy losses increased with increasing temperature, and exergy efficiency follows no specific trend [23]. Darvishi et al. [24] analysed energy and exergy of white mulberry using a fixed-bed microwave dryer. They reported that the specific energy consumption (SEC) was increased with increase in the the microwave power. They also showed that SEC ranged between 3.97 and 6.73 MJ/kg. Motevali et al. [4] studied SEC, energy efficiency and drying efficiency of hot-air, infrared, and hybrid IRHA dryers. They reported improved energy and exergy efficiencies for the hybrid dryer. In their study, the maximum energy efficiency (16.15%) occurred when using 0.49 W/cm² IR radiation at 40 °C and airflow velocity of 0.5 m/s. The minimum reported energy efficiency (3.37%) occurred when using 0.22 W/cm² IR radiation at 40 °C and airflow velocity of 1.5 m/s.

Literature review showed that there is no practical study on the exergy and energy analyses of hybrid infrared-hot air dryers. Therefore, here presented study analysed energy and exergy of the drying process for dog-rose flowers using a hybrid IRHA dryer.

MATERIALS AND METHODS

In this study, a hybrid infrared-hot-air dryer was used (Figure 1). Experiments were conducted at three radiation levels (0.22, 0.31 and 0.49 W/cm²), three temperatures (40, 50 and 60 °C), and three airflow velocities (0.4, 0.7 and 1 m/s). Dog-rose flowers were picked from Chaharmahal and Bakhtiari highlands. In order to determine the initial moisture content (MC), samples were placed inside the oven, and using weight

![Figure 1. Schematic of the hybrid IRHA dryer.](image-url)
changing the initial moisture content of samples was determined 0.85 (w.b.). In order to determine the IR radiation intensity, the distance between the emitter and the sample was changed. Distances between IR lamp and samples were 30, 20 and 10 cm for 0.22, 0.31 and 0.49 W/cm², respectively. Samples were laid on a 10 cm by 10 cm surface.

During drying experiments, mean range of ambient temperature variation was 28-32 °C and mean relative humidity was 24-31%. Air parameters were adjusted by measuring temperature and velocity using a thermometer (Lutron, Taiwan), anemometer (Anemometer, Lutron-YK, Taiwan) and humidity meter (Testo 650, 05366501, Germany). A digital balance (AND, model EK600i, Japan, 0.01 g) was used for weighing the samples. Also pressure gauge (PVR 0606A81, Italy) was used to measure the inner air pressure at dryer.

**Energy consumption**

The employed hybrid dryer consisted of three energy sources: IR emitter, heaters (thermal energy), and blowers (mechanical energy). The total thermal energy consumed by heaters and IR emitters during the drying process can be determined using Eq. (1) [4]:

\[ E_{\text{term}} = (A_\text{th}C_p\rho_A\Delta T + L_W) \times 60 \]  

For Eq. (1), air density and air specific heat capacity can be obtained from Eqs. (2) and (3), respectively [22]:

\[
\rho_a = 3 \times 10^{-8} (T_a - 273.15)^3 - 2 \times 10^{-5} (T_a - 273.15)^2 - 5.6 \times 10^{-3} (T_a - 273.15) + 1.2996
\]

\[
C_a = -7 \times 10^{-10} (T_a - 273.15)^3 + 7 \times 10^{-7} (T_a - 273.15)^2 - 7 \times 10^{-4} (T_a - 273.15) + 1.0042
\]

Moreover, the amount of mechanical energy consumed by the blower is determined using the following Eq. (4):

\[ E_{\text{mec}} = \Delta P V_{\text{bl}} t \times 60 \]

**Analysis of energy absorption by the samples**

When IR waves collide with the surface, their energy is distributed in several forms. A portion of their energy passes through the sample, another portion is absorbed by the sample, and the rest is reflected from the surface depending on the type of the sample (Figure 2).

The portion of the IR energy that is absorbed by the sample can be determined by Eq. (8) [25]:

\[
Q_{\text{abs}} = \frac{\sigma \left( T_M^4 - T_a^4 \right)}{A_{\text{IR}} \times \varepsilon_{\text{IR}}} + \frac{1}{(1/A_{\text{IR}} \times F_{\text{IR,m}}) + 1/(1/A_{\text{IR}} \times F_{\text{IR,dc}}) + (1/A_{\text{M}} \times F_{\text{M,dc}})} + \frac{1}{A_{\text{M}} \times \varepsilon_{\text{M}}}
\]

**Exergy balance and exergy ratio equations**

Exergy balance equation for an IRHA dryer is as follows [22]:

\[
\frac{W_r (e_{\text{ex,\text{in}}}}{\text{a,\text{out}} - e_{\text{ex,\text{in}}} + \Delta t} = \dot{E}_{\text{X,\text{in}}} - \dot{E}_{\text{X,\text{out}}}
\]

\[
+ \dot{E}_{\text{X,rad}} - \dot{E}_{\text{X,ref}} - \dot{E}_{\text{X,emit}} - \dot{E}_{\text{X,trans}} + \dot{E}_{\text{X,loss}} - \dot{E}_{\text{X,des}}
\]
Eq. (9) is briefed as follows [22]:

$$
\frac{W_a}{\Delta t} = \dot{E}_{\text{a,in}} - \dot{E}_{\text{a,out}} - \dot{E}_{\text{abs}} - \dot{E}_{\text{loss}} - \dot{E}_{\text{des}}
$$

(10)

The specific exergy of the product being dried is determined using Eq. 10 [24]:

$$
\dot{e}_m = C_m \left[ (T_m - T_0) - T_0 \ln \left( \frac{T_0}{T_m} \right) \right]
$$

(11)

The exergy rate of air is also determined using the following relation [26]:

$$
\dot{E}_a = M_a C_a \left[ (T_a - T_0) - T_0 \ln \left( \frac{T_0}{T_a} \right) \right]
$$

(12)

Since the velocities of air inflow and outflow and dryer section area were kept constant during the experiments, the air flow rates at inlet and outlet were equal:

$$
\dot{M}_{\text{a,in}} = \dot{M}_{\text{a,out}} = \dot{M}_a
$$

(13)

Exergy flux from an IR emitter with an emission intensity $\varepsilon_{\text{IR}}$ at a given temperature of the IR lamp was determined using Eq. (14) [27]:

$$
E_{\text{ex,IR}} = \sigma \varepsilon_{\text{IR}} T_{\text{IR}}^4 \left[ \varepsilon_{\text{IR}} + \frac{1}{3} \left( \frac{T_0}{T_{\text{IR}}} \right)^4 - \frac{4 \varepsilon_{\text{IR}}^{0.75} T_0}{3 T_{\text{IR}}} \right]
$$

(14)

Additionally, Eq. (15) was used for determining energy flux:

$$
E_{\text{HR}} = \varepsilon_{\text{HR}} \sigma T_{\text{HR}}^4
$$

(15)

In order to analyse exergy of a system for obtaining more reliable results, there should be a relation between its energy and exergy. Therefore, the quality factor $\beta$ was employed [22]:

$$
\beta = 1 + \frac{1}{3} \varepsilon_{\text{HR}} \left( \frac{T_0}{T_{\text{HR}}} \right)^4 - \frac{4 T_0^{0.75}}{3 T_{\text{HR}}^{0.25}}
$$

(16)

$$
\dot{E}_{\text{ex,abs}} = \beta Q_{\text{abs}}
$$

(17)

Exergy transfer rate from evaporation in the drying chamber was determined based on the following equation [24]:

$$
\dot{E}_{\text{ex,eva}} = \left( 1 - \frac{T_0}{T_m} \right) \dot{m}_{\text{eva}} \lambda
$$

(18)

In addition, the amount of exergy loss was determined using the following equation [22]:

$$
\dot{E}_{\text{ex,loss}} = \left( 1 - \frac{T_0}{T_m} \right) U A_{\text{DC}} (T_{\text{DC}} - T_0)
$$

(19)

The dryer housing wall temperature was given as follows:

$$
T_{\text{DC}} = \frac{T_{\text{a,in}} + T_{\text{a,out}}}{2}
$$

(20)

The exergy efficiency ($\eta_{\text{ex}}$) of the hybrid IRHA dryer was calculated as the ratio of the exergy consumed for drying products to the exergy entering the apparatus, which consisted of hot-air exergy plus exergy absorbed by the products. It was shown using the following equation:

$$
\eta_{\text{ex}} = \frac{\dot{E}_{\text{ex,eva}}}{\dot{E}_{\text{ex,abs}} + \dot{E}_{\text{ex,a,in}}}
$$

(21)

Some parameters which are constant in mentioned equations are given in Table 1.

Table 1. Data and parameters which used in energy and exergy equations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{\text{DC}}$</td>
<td>m$^2$</td>
<td>0.04</td>
</tr>
<tr>
<td>$A_{\text{HR}}$</td>
<td>m$^2$</td>
<td>0.081575</td>
</tr>
<tr>
<td>$A_m$</td>
<td>m$^2$</td>
<td>0.01</td>
</tr>
<tr>
<td>$F_{\text{IR,DC}}$</td>
<td>--</td>
<td>0.75</td>
</tr>
<tr>
<td>$F_{\text{IR,M}}$</td>
<td>--</td>
<td>0.25</td>
</tr>
<tr>
<td>$F_{\text{HR,DC}}$</td>
<td>--</td>
<td>0.95</td>
</tr>
<tr>
<td>$T_0$</td>
<td>K</td>
<td>304.65</td>
</tr>
<tr>
<td>$U$</td>
<td>kW/m$^2$K</td>
<td>0.0079</td>
</tr>
<tr>
<td>$\varepsilon_{\text{HR}}$</td>
<td>--</td>
<td>0.85</td>
</tr>
<tr>
<td>$\varepsilon_m$</td>
<td>--</td>
<td>0.72</td>
</tr>
<tr>
<td>$\rho_a$</td>
<td>kg/m$^3$</td>
<td>1.04552</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>kW/m$^2$K$^4$</td>
<td>5.67×10$^{-4}$</td>
</tr>
<tr>
<td>$L_P$</td>
<td>kW</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Experimental uncertainty

The analysis of uncertainties in experimental measurements is a powerful tool, particularly when it is used in the planning and the design of experiments. Uncertainties analysis is given in Eq. (22) [28]:

$$
W_R = \left[ \left( \frac{\delta R}{\delta X_1} W_1 \right)^2 + \left( \frac{\delta R}{\delta X_2} W_2 \right)^2 + \ldots + \left( \frac{\delta R}{\delta X_n} W_n \right)^2 \right]^\frac{1}{2}
$$

(22)

During the experiments, total uncertainties of measured parameters and calculated experimental parameters were presented in Table 2.
Table 2. Uncertainties of the parameters drying experiment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty of the measurement of relative humidity of air</td>
<td>RH</td>
<td>±0.1</td>
</tr>
<tr>
<td>Uncertainty in measurement of moisture quantity</td>
<td>g</td>
<td>±0.001</td>
</tr>
<tr>
<td>Uncertainty of the measurement of ambient air temperature</td>
<td>°C</td>
<td>±0.21</td>
</tr>
<tr>
<td>Inlet temperature</td>
<td>°C</td>
<td>±0.21</td>
</tr>
<tr>
<td>Outlet temperature</td>
<td>°C</td>
<td>±0.21</td>
</tr>
<tr>
<td>Ambient air temperature</td>
<td>°C</td>
<td>±0.21</td>
</tr>
<tr>
<td>Air velocity</td>
<td>m/s</td>
<td>±0.33</td>
</tr>
<tr>
<td>Mass loss measurement</td>
<td>g</td>
<td>±0.5</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Energy analysis

In Figure 3 are shown energy efficiency variations against time for the IR-HA dryer at 40 °C using different IR radiation levels and airflow velocities. The highest energy efficiency (54.89%) was achieved for that temperature using IR radiation intensity of 0.49 W/cm² and airflow velocity of 0.4 m/s; whereas its lowest level (3.02%) was recorded when using IR radiation intensity of 0.22 W/cm² and airflow velocity of 1 m/s. Nowak and Lewicki [29] showed that increasing air velocity caused decrease of evaporation temperature during the drying process.

In Figure 4 are plotted energy efficiency variations and energy losses against time for the IR-HA dryer at 50 °C using different IR radiation levels and airflow velocities. The highest energy efficiency (53.56%) was achieved at 50 °C using IR radiation intensity of 0.49 W/cm² and airflow velocity of 0.4 m/s; whereas the lowest level (3.04%) was recorded for IR radiation intensity of 0.22 W/cm² and airflow velocity of 1 m/s.

As shown in Figure 5, the highest energy efficiency (92.21%) was achieved at 50 °C using IR radiation intensity of 0.49 W/cm² and airflow velocity of 0.4 m/s; whereas its lowest level (3.2%) was recorded when using IR radiation intensity of 0.22 W/cm² and airflow velocity of 1 m/s.

Results from Figs. 3–5 showed that the high MC at the beginning of the drying process led to more...
Figure 4. Energy efficiency variations against time at different IR radiation levels and airflow velocities (50 °C).

energy absorption and more evaporation. Thus the energy efficiency had a steep initial increase. However, moisture loss levels were negligible during following time intervals, which in turn considerably dropped the energy efficiency during the drying time. At the same time, energy efficiency increased with increase in the IR radiation, incoming air temperature and reduced airflow velocity. On the other hand, it decreased with the decrease in IR radiation and air temperature while at the same time increased the airflow velocity. Faster airflow velocities at the inlet made the sample surface cooler, which in turn led to slower evaporation from the surface and reduced the evaporation rate. Özdemir et al. [30] have shown that IRHA enhanced the drying process due to the fact that the heat transfer was simultaneously achieved by
both radiation and convection. As a result, moisture variations with respect to energy consumption decreased with increase in the airflow velocity at the inlet. Since a part of energy transfer to the samples is consumed for heating them at the beginning of the process, energy efficiency is lowest at low temperatures and low IR radiation levels. Since a large portion of the energy input is spent on initial heating of the samples it took a long time to reach the evaporation phase. On the contrary, samples could be quickly heated up using high radiation and temperature levels, resulting in quick evaporation and higher energy efficiency. Effective moisture diffusion increased with decreased MC in the samples. This is due to the increase in sample temperature as a result of heat generation inside the sample. As the radiation
level and incoming air temperature were increased, the rate of effective moisture diffusion increased and the drying time decreased. As a result, energy efficiency was increased. Higher levels of radiation and incoming air temperature accelerated the evaporation rate for moisture molecules for the studied samples. This, in turn, led to a faster reduction in the sample MC and thus an increase in energy efficiency Pathare and Sharma [31]; Reyes et al. [32]; Darvishi et al. [24]. The mean largest energy efficiency (9.11%) was achieved at 60 °C using airflow velocity of 0.4 m/s and radiation level of W/cm². Results are in good agreement with those reported by Motevali et al. [3,4], Sarker et al. [26] and El-Mesery and Mwithiga [8].

Exergy analysis

In Figure 6 shown are variations in exergy efficiency and exergy destruction against drying time at

![Graphs showing exergy efficiency and exergy destruction variations against time at different IR radiation levels and airflow velocities (40 °C).]
40 °C using different radiation and airflow velocity levels. Results revealed that, by increasing radiation and decreasing inflow velocity, the exergy efficiency was increased. Moreover, as the drying time passed and the energy losses increased, the exergy efficiency followed a falling trend whereas the exergy destruction took a rising one. The highest exergy efficiency (7.90%) was achieved at the temperature of 40 °C using IR radiation intensity of 0.49 W/cm² and airflow velocity of 0.4 m/s; whereas its lowest level (3.98 %) was recorded when using IR radiation intensity of 0.22 W/cm² and airflow velocity of 1 m/s.

In addition, for the same temperature, the highest exergy destruction (0.47 kJ/s) occurred when IR radiation intensity of 0.22 W/cm² and airflow velocity of 1 m/s were used; whereas its lowest value (0.25 kJ/s) was recorded for IR radiation intensity of 0.49 W/cm² and airflow velocity of 0.4 m/s.

According to Figure 7, exergy destruction at 50 °C increased with a milder slope than at 40 °C. At the

![Figure 7. Exergy efficiency and exergy destruction variations against time at different IR radiation levels and airflow velocities (50 °C).](image-url)
same time, the exergy efficiency maintained its falling trend during the drying time and finally approximated zero. The sample MC almost reached zero value when energy absorption was very low and more energy was spent on heating the surface area of the sample. Accordingly, the exergy efficiency also approached zero. The highest exergy efficiency (12.58%) was achieved at this temperature (50 °C) using IR radiation intensity of 0.49 W/cm² and airflow velocity of 0.4 m/s; whereas its lowest level (5.09%) was recorded when using IR radiation intensity of 0.22 W/cm² and airflow velocity of 1 m/s. In addition, at the same temperature, the highest exergy destruction (0.40 kJ/s) occurred when IR radiation intensity of 0.22 W/cm² and airflow velocity of 1 m/s were used; whereas its lowest value (0.17 kJ/s) was recorded for IR radiation intensity of 0.49 W/cm² and airflow velocity of 0.4 m/s.

In Figure 8 variations in exergy and exergy destruction at 60 °C are presented. The highest exergy efficiency (23.65%) was achieved at 60 °C using IR radiation intensity of 0.49 W/cm² and airflow velocity

![Figure 8. Exergy efficiency and exergy destruction variations against time at different IR radiation levels and airflow velocities (60 °C).](image)
of 0.4 m/s; whereas its lowest level (4.39%) was recorded when using IR radiation intensity of 0.22 W/cm² and airflow velocity of 1 m/s. At the same temperature, the highest exergy destruction (0.36 kJ/s) also occurred when using IR radiation intensity of 0.22 W/cm² and airflow velocity of 1 m/s; whereas its lowest amount (0.09 kJ/s) was recorded for IR radiation intensity of 0.49 W/cm² and airflow velocity of 0.4 m/s.

According to the results shown in Figs. 6-8, the exergy efficiency value decreased and approached zero as the drying time passed. Results revealed that more energy was absorbed by samples for increasing IR radiation intensity and raising incoming air temperature. This, in turn, accelerated heat and mass transfers inside samples. In other words, higher IR radiation and air temperature levels led to increased sample surface temperature, higher moisture pressure, and increased moisture diffusion inside and on the surface of the samples. The same effect caused the evaporation exergy to rise and, as shown in Eq. (18), the exergy efficiency was improved. Furthermore, higher incoming air velocity reduced the exergy efficiency under all conditions due to higher levels of airflow velocity cooled down the sample surface, leading to decreased variations in its MC. As shown in Figs. 6-8, the exergy destruction level, unlike exergy efficiency, was increased over time when energy absorption decreased. Accordingly, as the exergy efficiency approached zero, the exergy destruction moved towards its maximum value. Results showed that exergy destruction had an inverse relationship with IR radiation and incoming air temperature levels. It also increased when using higher airflow velocities, as its largest level (0.471 kJ/s) occurred at 40 °C using IR radiation of 0.22 W/cm² and airflow velocity of 1 m/s. The lowest exergy destruction level was 0.085 kJ/s for IR radiation of 0.49 W/cm² and airflow velocity of 0.4 m/s at 60 °C. Results are in agreement with those reported by Darvishi et al. [24], Aghbashlo [22], Erbay and Icier [33], Ranjbaran and Zare [34] and Acevedo [18].

CONCLUSION

The present study analysed energy and exergy of a hybrid Infrared-hot-air dryer for drying dog-rose flowers. Final outcomes of this study are very important for industrialists and farmers in order to choose the best conditions for drying process using IR-Hot air to secure the highest performance and lowest energy consumption and costs as listed:

- Energy and exergy efficiencies for the drying process follow a rising trend at the early stages; however, they approach zero by the end of the process. On the contrary, as the drying time passes, there is an increase in energy loss, exergy destruction and exergy loss.
- Results also revealed that increasing the IR radiation intensity and the incoming air temperature not only reduced the drying time, but also improved energy and exergy efficiencies. According to this conclusion, the best drying performance occurred for highest inlet air temperature and IR intensity that were 60 °C and 0.49 W/cm², respectively.
- Increasing the airflow velocity had an inverse effect on energy efficiency and exergy efficiency. Accordingly, by increasing the airflow velocity, energy and exergy efficiencies decreased. As mentioned before, by changing velocity from 0.4 to 1 m/s surface of the samples would cool down. Thus, the best air velocity for drying in this dryer was 0.4 m/s. Note, the air velocity cannot be zero because evaporated water should be extracted from the inside of dryer chamber.

The general conclusion from this research is that a minimum airflow velocity was required to remove moisture and prevent from ambient moisture saturation. The best conditions for achieving the maximum energy and exergy efficiencies consisted of IR radiation intensity of 0.49 W/cm², air temperature of 60 °C, and airflow velocity of 0.4 m/s. It seems that this conclusion can be extended for other wet product similar to dog-rose. Other agricultural products could be dried using this method and under the conditions resulted from this study.

REFERENCES

UTICAJ IR INTENZITETA I TEMPERATURE VAZDUHA NA EKSERGIJU I ENERGIJU HIBRIDNE INFRACRVENE SUŠARE

Ovaj rad analizira potrošnju energije i eksergije za sušenje cveta ruže pomoću hibridne infracrvene i konvektivne sušare na tri intenziteta infracrvenog (IR) zračenja, tri brzine protoka vazduha i tri temperature sušenja. Rezultati pokazuju da su efikasnosti energije i eksergije povećane naročito na početku sušenja. Gubici energije, ireverzibilnost i gubitak eksergije rastu sa povećanjem IR intenziteta, porastom temperature vazduha i snimanjem protoka vazduha. Prosečno najniže energetske i eksergijske efikasnosti bile su 5,76 i 3,98%, redom, posmatrano na temperaturi vazduha od 40°C, pri intenzitetu IR zračenja od 0,22 W/cm² i protoku vazduha od 1 m/s. Prosečne vrednosti najviših vrednosti energije i eksergije bila su 49,92 i 23,65% na početku procesa sušenja na 60°C pri intenzitetu IR zračenja od 0,49 V/cm² i protoku vazduha od 0,4 m/s.

Ključne reči: ruža, temperatura vazduha, IR intenzitet, eksergija, energija, sušenje.